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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: Vahid Tarokh et al.
Serial No. 09/977,540
Filed: 10/15/2001
For: **EFFICIENT OFDM COMMUNICATIONS WITH INTERFERENCE IMMUNITY**

Examiner: Jung, Min
Art Unit: 2663

Mail Stop Amendment
Commissioner for Patents
PO Box 1450
Alexandria, VA 22313-1450

Sir:

DECLARATION UNDER 37 C.F.R. § 1.131

1. My name is Wen Tong, and I am one of the named inventors for the application identified above.

2. The other inventors are no longer associated with my employer and are unavailable to execute the current declaration.

3. Together with my co-inventors, I helped conceive of this invention by at least January 2001. Together with Vahid Tarokh, I helped prepare a document entitled "memo_2.pdf" memorializing our conception of the current invention. A copy of this document is attached as Exhibit A. This document was modified at least on January 18, 2001 as evidenced by the screen shot attached as Exhibit B.

4. From January 2001 to April 2001, my co-inventors and I polished the document originally begun by at least January 2001. This work continued until the end of April 2001 when I submitted an invention disclosure document to my employer. A copy of this invention disclosure document is attached as Exhibit C. Attached to this invention disclosure document was a finalized version of the paper originally begun in January 2001. This finalized version is attached as Exhibit D.

5. Both the papers of Exhibit A and Exhibit D fully disclose the invention currently being claimed in claims 1-5, 7-11, 13-15, 17-19, 21-23, and 25-27 of the application. Claims 1-5, 7-11, 13-15, 17-19, 21-23, and 25-27 remain essentially unchanged from their filing.

6. The invention disclosure document of Exhibit C is stamped as received by my employer on May 1, 2001.

7. My employer has a first in, first out policy concerning invention submissions and my invention submission was considered in the ordinary course of this policy on May 25, 2001, as evidenced by the review form attached as Exhibit E. This document reflects a target filing date of October 1, 2001.

8. On August 28, 2001, my employer sent the invention submission to outside counsel so that outside counsel could prepare the application, as evidenced by the letter attached as Exhibit F. Outside counsel acknowledged receipt of the instructions on August 29, 2001 as evidenced by attached Exhibit G.

9. Outside counsel worked on a first in-first out system and worked on this application according to this policy. Outside counsel spoke with the inventors on September 5, 2001 as evidenced by the calendar print out attached as Exhibit H.

10. During September 2001, outside counsel and the inventors worked on perfecting the application as evidenced by the facsimile coversheets dated September 5 and 6, 2001 attached as Exhibit I.

11. On September 17, 2001, outside counsel provided a first draft of the application to the inventors as evidenced by the facsimile coversheet attached as Exhibit J.

12. On September 19, 2001, inventor comments were returned to outside counsel as evidenced by the facsimile coversheet attached as Exhibit K.

13. The application was finalized and a final draft was sent with formal paperwork on September 25, 2001 as evidenced by the facsimile coversheet attached as Exhibit L. The inventors executed the paperwork and returned the paperwork to outside counsel.

14. The application was filed October 15, 2001.

15. I hereby declare that all declarations made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Wen Tong

Oct. 20, 2005
Date

EXHIBIT A

A Proposal for a Bandwidth Efficient High Data Rate Wireless System Based on No Frequency Reuse, Interference Suppression Techniques and Space-Time Block Coded OFDM

Vahid Tarokh *Wen Tong*

[redacted]

Abstract

We propose a cellular system based on an OFDM (orthogonal frequency division multiplexing) implementation where the the transmission from different base stations are synchronized to the same clock. We assume frequency reuse factor equal to one (no frequency reuse). The transmission in downlink employs space-time block codes. We demonstrate that out-of cell interference can be effectively rejected by employing novel techniques that use the structure of space-time block codes.

1 Introduction

The most important source of noise in a cellular system is interference. In the absence of out-of-cell and inter-cell interference, the capacity of wireless systems is limited only by the thermal noise and is extremely large.

For any receiver, interference can be either caused by out of cell transmitters operating on the same frequency, or by transmitter(s) operating in the same cell. In some occasions, echoes of the signal destined to a user can cause interference (in the form of ISI). This scenario will be referred to as *self-interference*. In other cases, signals destined to other receivers are the cause of interference. In addressing the issues of interference, communication theorists have produced a substantial amount of literature.

A standard approach to combat interference is to share time, frequency and spatial resources amongst different users. A standard examplo is the so-called frequency planning technique where

the neighbouring cells do not operate on the same frequency at the same time. This approach is employed in the current TDMA systems, but is far from being efficient as it suffers a bandwidth penalty.

An interesting approach to combat interference in cellular systems is multiuser detection (MUD) in combination with CDMA. This is hard to implement at the receiver end, since the transmission from different base stations do not arrive synchronously at the receiver. Moreover, the remote units are usually small and power limited, making it difficult to implement algorithms requiring a large amount of computation such as MUD techniques.

Affiliated with the use of CDMA is self-interference and the interference from the signals destined to other users within the same cell. This can be overcome to some extent if the transmission sequences for different users within a cell are orthogonal (as is the case in the HDR system). However, out of cell interference remains a major issue. In the HDR system, more than half of the users experience signal to interference plus noise ratios (SINR) of less than zero dB. This limits the data rates that can be provided to these users if the system treats the interference as noise.

An efficient cellular system should enjoy frequency reuse factor equal to one, meaning that all the available bandwidth is used in every cell. Such an implementation reduces the SINR of the users closer to the edge (border) of each cell. For these remote units, the desired signal has almost the same power as the signals transmitted from the neighboring base stations, since the distances of the unit from these transmitters are almost equal. If the interference is treated as noise, this low SINR limits the data rate that can be provided to these remote units. Because of the *fairness factor* of the system, admission of these remote units into the system will limit the maximum throughput of the system. Hence, even those remote units enjoying strong SINR will be penalized. This can make the system highly inefficient.

It may seem that the aforementioned problem can be overcome by rejecting the users with low SINR. This is not a practical solution, as any commercial wireless data solution has to be able to provide services to users at any location in the cell. In this light, a solution must be provided that improves the data rate of the users at the edge of each cell even in the presence of strong interference. *This is an issue addressed in the present document.*

Another major impairment of wireless channels is *fading*. Fading is caused by the destructive addition of the reflections of the desired signal. When a receiver is in fade, it cannot receive the desired signal. The resource to combat fading is called *diversity*. By diversity, we mean that another replica of the desired signal is provided to the receiver in another format. Diversity resources include

- temporal diversity, where another replica of the transmitted signal is sent to the receiver at another time,
- frequency diversity, where another replica of the transmitted signal is sent to the receiver in another frequency, and
- spatial diversity, where multiple transmitter (Tx) and receiver (Rx) antennas are used for sending/receiving another replica of the transmitted signal.

Temporal and frequency resources are precious. In this light, spatial diversity is an interesting resource as it does not have a time and frequency penalty. In order to benefit from spatial diversity, Rx antennas should not be too close to each other or else must use different polarization. Similarly, there must be a reasonable distance between the Tx antennas. Because of the limitation on the size of remote units, only a limited number of receive antennas can be used. The deployment of multiple transmit antennas is relatively easier, as the cost of the depolyment can be amortized between many users. Another ingredient of this work, is the *use of multiple Tx antennas at the base station and multiple Rx antennas at the remote units with the combination of appropriate coding techniques* [6]. This reduces the effect of fading significantly.

In order to combine the benefit of multiple antennas with interference suppression, we will use *OFDM* (orthogonal frequency division multiplexing) as our preferred transmission scheme. Such an implementation greatly reduces self interference (ISI) as well as synchronization problems and makes it much easier to implement multiuser detection (MUD). Indeed, *we will argue that MUD fits much easier in an OFDM implementation compared to CDMA.* Surprisingly, most of the existing literature on MUD considers a CDMA framework.

The combination of spatial diversity, MUD in an OFDM framework, and the abolishment of frequency reuse is the point of departure of our proposed system from the existing systems. These enhancements make our system very suitable for providing high wireless data rates.

2 The Proposed System

Our proposed system uses OFDM [4] for downlink transmission. We further assume that all the base stations use all the available bandwidth for transmission and that all the stations are synchronized to the same clock. Each base station is equipped with n Tx antennas and each remote unit is equipped with m Rx antennas. OFDM transmission in downlink is done using N tones. At each

time $t = 0, T, 2T, \cdots$, data bits $\mathbf{b}(t)$ (not necessarily having the same number of bits) arrive at the encoder of each base station $B_l, l = 1, 2, , \cdots, L$. The ensemble of these data bits $\mathbf{b}(0), \mathbf{b}(T), \mathbf{b}(2T), \cdots$ choose n blocks of N constellation symbols $c_{1,i,B_l}(t)c_{2,i,B_l}(t)\cdots c_{N,i,B_l}(t)$, $i = 1, 2, \cdots, n$ for each time $t = 0, T, 2T, \cdots$. Each block of N symbols is the input to an IFFT device. To the output of the IFFT symbol a cyclic extension of length M is appended to produce a time domain symbol. This procedure produces n time domain symbols and these symbols are modulated and transmitted simultaneously from the n transmit antennas. Let us assume that each OFDM symbol has duration T and the time length of the cyclic extension in each OFDM symbol is ν.

The transmitted signals arrive at the receiver after traveling through the wireless channels. At the receiver, the received signal of each Rx is first down-converted. The cyclic prefix is removed. The remaining N samples are the input to an FFT device. Assuming that the delay spread of the channel is is less than ν and the k-th output of the FFT device of the Rx chain j is given by $r_{k,j,B_l}(t)$, and ignoring the effect of the interference from the signals transmitted from other base station, we have

$$r_{k,j,B_l}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_l}(t)c_{k,i,B_l}(t) + \eta_{k,j}(t), \tag{1}$$

where $\alpha_{i,j,B_l}(t)$ is the complex number representing the total effect of the channel from Tx antenna i of base station B_l to Rx antenna j at time t and $\eta_{k,j}(t)$ is Gaussian noise. Throughout this work, it will be assumed that $\alpha_{i,j,B_l}(t)$ is constant during the transmission of a symbol.

3 Interference

In this section, we will consider the effect of the interference from other base stations on the users close to the edge of each cell. To begin with, let us recall that the wireless channel is a linear channel and therefore the signals transmitted from different base stations superpose linearly in the transmission media. In the previous section, it was discussed that the contribution of the signals transmitted from base station B_l to the k-th output of the FFT device for the Rx chain j of the receiver is given by Equation (1), provided that the delay spreads $\Delta(i, j, B_l), i = 1, 2, \cdots, n$ of the channels from the Tx antennas $i = 1, 2, \cdots, n$ of base station B_l to the Rx chain j of the receiver are less than the cyclic prefix duration ν.

Let us suppose the receiver is synchronized to the transmissions from base station B_l. Because the distance of the receiver from the base station $B_{l'}$ and the base station B_l are different, there is a time difference $t_{l'}$ between the times that it takes for the elctromagnetic waves to travel from respectively

base station $B_{l'}$ and B_l to the receiver. Because of the time difference $t_{l'}$, signals from the Tx chains $i = 1, 2, \cdots, n$ of base station $B_{l'}$ arrive within at most the time period $t_{l'} + \Delta(i, j, B_{l'}), i = 1, 2, \cdots, n$ from the sampling instances at the Rx chain j. Provided that $t_{l'} + \Delta(i, j, B_{l'}) \leq \nu$ for $i = 1, 2, \cdots, n$, the contribution of the signals transmitted from base staion $B_{l'}$ to the k-th output of the FFT device of the Rx chain j is given by

$$r_{k,j,B_{l'}}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_{l'}}(t) c_{k,i,B_{l'}}(t), \quad j = 1, 2, \cdots, m, \tag{2}$$

where $\alpha_{i,j,B_{l'}}(t)$ is the complex number representing the total effect of the channel from Tx antenna i of base station $B_{l'}$ to Rx antenna j at time t. It will be assumed that $\alpha_{i,j,B_{l'}}(t)$ is constant during the transmission of a symbol.

An important observation is made next. Let us consider two neighboring cells corresponding to the base stations B_l and $B_{l'}$. If the remote unit considered above is close to the boundary of these cells, then it has almost the same distance from B_l and $B_{l'}$. We conclude that the time difference $t_{l'}$ is small. This means that if the system is designed such that the duration of the cyclic prefix is slightly larger than the typical delay spreads observed in the propagation environment, then the contribution of the signals transmitted from $B_{l'}$ to the k-th output of the FFT device of the Rx chain j is given by Equation (2). The contributions of the base stations far from the remote unit are small and thus the k-th output of the FFT device of the Rx chain j is approximately given by

$$r_{k,j}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_l}(t) c_{k,i,B_l}(t) + \sum_{B_{l'}} \sum_{i=1}^{n} \alpha_{i,j,B_{l'}}(t) c_{k,i,B_{l'}}(t) + \eta_{k,j}(t), \tag{3}$$

where $B_{l'}$ runs in the set of all the neighboring base stations of B_l.

The above equation is remarkable in the sense that *the interference and the desired signal are synchronized.* This is not the case for CDMA systems! *An important conclusion to be made here is that OFDM is a much more appropriate framework for multiuser detection and interference suppression techniques than CDMA.* This observation was first made in [2].

Whenever the remote unit is much closer to the base station B_l than other base stations, then the interference is small and may be treated as noise. Even for these users, if the cyclic prefix time is moderately large, the interfering signals can be treated as synchronous interference and the technique we propose in the next section can potentially provide significant improvements.

4. Space-Time Block Coded interference Suppression

We next consider the use of space-time block codes [1, 5] in the above scenario. Space-time block codes are interesting, because they provide remarkably simple decoding algorithm based only on linear processing at the receiver. Moreover, they support a simple interference suppression algorithm [3].

To keep the presentation simple, we assume that the number of Tx antennas $n = 2$, but the generalization to higher numbers of antennas is straightforward. We assume that the signal constellation has 2^b elements. We will only present the results for the uncoded case, as the generalization to the coded case is straightforward. Indeed any coding scheme can be concatenated with the transmission strategy described below.

At the encoder, at times $t = 0, 2T, 4T, \cdots$, a block of $2bN$ bits $\mathbf{b}(t)$ arrive at the encoder of base station B_l. These $2bN$ bits pick up two blocks of length N of constellation symbols $s_{1,1,B_l}(t), s_{2,1,B_l}(t), \cdots, s_{N,1,B_l}(t)$ and $s_{1,2,B_l}(t), s_{2,2,B_l}(t), \cdots, s_{N,2,B_l}(t)$. The encoder now lets

$$c_{i,1,B_l}(t) = s_{i,1,B_l}(t), \tag{4}$$

$$c_{i,2,B_l}(t) = s_{i,2,B_l}(t), \tag{5}$$

for $t = 0, 2T, 4T, \cdots,\ i = 1, 2, \cdots, N$ and

$$c_{i,1,B_l}(t) = -s^*_{i,2,B_l}(t - T), \tag{6}$$

$$c_{i,2,B_l}(t) = s^*_{i,1,B_l}(t - T), \tag{7}$$

for $t = T, 3T, 5T, \cdots,\ i = 1, 2, \cdots, N$ (see Section 2). This is precisely the scheme of [1] applied to each carrier. The transmission and reception is now done as described in Section 2. It will be assumeid that all the base stations use space-time block coding for downlink transmission. As in previous sections, it will also be assumed that all the base stations are synchronized to the same clock.

At the remote unit, following the application of FFT, the k-th output of the FFT device of the Rx chain j of the remote unit is given by:

$$r_{k,j}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_l}(t) c_{k,i,B_l}(t) + \sum_{B_{l'}} \sum_{i=1}^{n} \alpha_{i,j,B_{l'}}(t) c_{k,i,B_{l'}}(t) + \eta_{k,j}(t), \tag{8}$$

where $B_{l'}$ runs in the set of all the neighboring base stations of B_l (see Section 3).

In particular

$$r_{k,j}(0) = \alpha_{1,j,B_l}(0)s_{k,1,B_l}(0) + \alpha_{2,j,B_l}(0)s_{k,2,B_l}(0) + \sum_{B_{l'}} \left(\alpha_{1,j,B_{l'}}(0)s_{k,1,B_{l'}}(0) + \alpha_{2,j,B_{l'}}(0)s_{k,2,B_{l'}}(0)\right) + \eta_{k,j}(0), \tag{9}$$

and

$$r_{k,j}(T) = -\alpha_{1,j,B_l}(T)s^*_{k,2,B_l}(0) + \alpha_{2,j,B_l}(T)s^*_{k,1,B_l}(0) + \sum_{B_{l'}} \left(-\alpha_{1,j,B_{l'}}(T)s^*_{k,2,B_{l'}}(0) + \alpha_{2,j,B_{l'}}(T)s^*_{k,1,B_{l'}}(0)\right) + \eta_{k,j}(T). \tag{10}$$

We assume that $\alpha_{i,j,B_l}(0) \simeq \alpha_{i,j,B_l}(T)$ for $i = 1, 2$ and $\alpha_{i,j,B_{l'}}(0) \simeq \alpha_{i,j,B_{l'}}(T)$ for $l' \neq l$ and $i = 1, 2$. This is equivalent to the assumption that the channels from Tx antennas of base stations to the Rx antennas of the remote unit do not change signifiantly over the period of two OFDM symbols. This is a reasonable assumption given the parameters of practical OFDM systems and the speed of remote units.

For notational simplicity, we let

$$h_{i,j,l} = \alpha_{i,j,B_l}(0) = \alpha_{i,j,B_l}(T), \tag{11}$$

$$h_{i,j,l'} = \alpha_{i,j,B_{l'}}(0) = \alpha_{i,j,B_{l'}}(T), \tag{12}$$

then the above equations are written as

$$r_{k,j}(0) = h_{1,j,l}s_{k,1,B_l}(0) + h_{2,j,l}s_{k,2,B_l}(0) + \sum_{l'} \left(h_{1,j,l'}s_{k,1,B_{l'}}(0) + h_{2,j,l'}s_{k,2,B_{l'}}(0)\right) + \eta_{k,j}(0), \tag{13}$$

$$r_{k,j}(T) = -h_{1,j,l}s^*_{k,2,B_l}(0) + h_{2,j,l}s^*_{k,1,B_l}(0) + \sum_{l'} \left(-h_{1,j,l'}s^*_{k,2,B_{l'}}(0) + h_{2,j,l'}s^*_{k,1,B_{l'}}\right) + \eta_{k,j}(T). \tag{14}$$

Letting

$$\mathbf{H}_{j,l} = \begin{pmatrix} h_{1,j,l} & h_{2,j,l} \\ -h^*_{2,j,l} & h^*_{1,j,l} \end{pmatrix}, \tag{15}$$

$$\mathbf{H}_{j,l'} = \begin{pmatrix} h_{1,j,l'} & h_{2,j,l'} \\ -h^*_{2,j,l'} & h^*_{1,j,l'} \end{pmatrix}, \tag{16}$$

$$\mathbf{s}_{k,l} = \begin{pmatrix} s_{k,1,B_l}(0) \\ s_{k,2,B_l}(0) \end{pmatrix}, \tag{17}$$

$$\mathbf{s}_{k,l'} = \begin{pmatrix} s_{k,1,B_{l'}}(0) \\ s_{k,2,B_{l'}}(0) \end{pmatrix}, \tag{18}$$

$$\eta_{k,j} = \begin{pmatrix} \eta_{k,j}(0) \\ \eta^*_{k,j}(T) \end{pmatrix}, \tag{19}$$

and

$$\mathbf{r}_{k,j} = \begin{pmatrix} r_{k,j}(0) \\ r^*_{k,j}(T) \end{pmatrix}, \tag{20}$$

we can write the above equations as

$$\mathbf{r}_{k,j} = \mathbf{H}_{j,l}\mathbf{s}_{k,l} + \sum_{l'} \mathbf{H}_{j,l'}\mathbf{s}_{k,l'} + \eta_{k,j}, \tag{21}$$

for $j = 1, 2, \cdots, m$.

For $m = 2$, and one interfering base station, the above equations are similar to the equations (15) and (19) of [3]. Naguib et al. consider a TDMA system where synchronization of the interfering and the desired signals is extremely difficult. Naguib [3] proves that assuming perfect synchronization of the interfering and the desired signals, given $m \geq 1$ receive antennas, the remote unit is able to completely suppress signals transmitted from all the Tx antennas of $k < m$ interfering base stations while obtaining a diversity advantage of $2(m - k)$. A simple zero forcing algorithm is also provided in [3]. This simple method preserve the benefits of Tx diversity for each user while suppressing the interference. Furthermore, an MMSE simple interference suppression algorithm is given in [3] that reduces the interference from interfering base stations and can provide a better performance than the aforementioned zero forcing algorithm when the SINR of the remote station is relatively large.

Because, our OFDM approach combined with space-time block coding provides perfect synchronization of the interfering and the desired signals, all the methods proposed in [3] easily apply to our case. Indeed, although Naguib's algorithms are proposed for TDMA systems, it turns out that thaey are *more natural to an OFDM framework* since OFDM naturally provides synchronization of the interfering and the desired signals. The MMSE approach of Naguib [3] has the zero-forcing approach as its subset and is therefore uniformly applicable to the remote units closer to the border of neighbouring cells and also to the remote units enjoying stronger SINR.

Alternative techniques exist in the literature that are also applicable for joint detection of the desired and interfering signals. Such techniques have been extensively studied in in the context of joint decoding and mutiuser detection for TDMA and CDMA systems. Nonetheless, they are not

easily implementable in these frameworks because of lack of synchronization of the interfering and the desired signals.

5 Conclusion

We have proposed a cellular system with no frequency reuse where the transmission in downlink employs OFDM. It was argued that this implementation provides effortless synchronization of the interfering and the desired signals. We proposed the use of space-time block codes at the base station with interference suppression techniques appropriate to space-time block codes. These techniques were previously proposed for TDMA systems in [3] but are not easily implementable in TDMA framework because of the lack of synchronization of the interfering and the desired signals. Alternative detection techniques such as joint decoding can also be applied in the OFDM framework proposed in this note. These techniques will be further exploited in a subsequent memorandum.

In conclusion, because of the the choice of OFDM framework, it was shown that the interference from neighbouring base stations can be suppressed while achieving Tx antenna diversity. We believe that this substantial advantage can be used to provide much higher data rates.

References

[1] S.M. Alamouti, "A simple transmitter diversity scheme for wireless communications," *IEEE Journal on Selected Areas of Communications*, Vol. 16, No. 8, pp. 1451–1458, Oct. 1998.

[2] K.L. Baum and N.S. Nadgauda, "Synchronous coherent orthogonal frequency division multiplexing system, method, software and device ," United States Patent 5,867,478, United States Patent Office, 1999.

[3] A.F. Naguib, N. Seshadri and A.R. Calderbank, "Applications of space-time block codes and interference suppression for high capacity and high data rate wireless systems," Thirty-Second Asilomar Conference on Signals, Systems & Computers, Volume: 2, pp. 1803-1810, 1998.

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[5] V. Tarokh, H. Jafarkhani and A.R. Calderbank, "Space-time block codes from orthogonal designs", *IEEE Trans. Inform. Theory*, Vol. 45, No. 5, pp. 1456-1467, July 1999.

[6] V. Tarokh, N. Seshadri and A.R. Calderbank, "Space-time codes for high data rate wireless communication: performance analysis and code construction," *IEEE Trans. Inform. Theory*, pp. 744–765, Mar. 1998.

EXHIBIT B

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Tarokh

[redacted]

Tarokh

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See also:
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figgensnr12.txt	1 KB	Text Document	5/18/2001 1:25 PM
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HubauxLGHBBVD0.pdf	241 KB	Adobe Acrobat Doc...	5/26/2001 8:13 PM
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Invention Disclosure Submission Reply

Disc No:		Received Date:	30 apr 2001
Disclosure Title:	Bandwidth Efficient High Data Rate Wireless System Based on Space-Time Block Coded OFDM, no Frequency Reuse and Interference Suppression Techniques		

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---=== Inventors ===--- 14545RO

Global Id	Name	Work Info	Home Info
[redacted]	HR Name: RATNARAJAH, THARAMLINGAM Known As: THARAMLINGAM [redacted]	[redacted]	[redacted]
[redacted]	HR Name: TONG, WEN Known As: TONG Email: [redacted]	[redacted]	[redacted]

---=== Attachments ===---

[redacted]

<End of Attachments>

Were there additional inventors involved?	yes	[redacted]	
Name of Supervisor or Divisional Head		Name of VP	
CLAUDE ROYER		ALAUDDIN JAVED	
LOB:	WIRELESS INTERNET	Business Unit:	WIRELESS-INTERNET
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Inside Nortel - Whom?		Outside Nortel - Whom?	
Inside Nortel - When?		Outside Nortel - When?	
NDA:	yes		

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Are you aware of any imminent future disclosures? Please provide dates and details.

Keywords for Searching:	Products that will use this invention:

Does this invention arise from any arrangement involving an external organization [redacted]

Is this invention relevant to a Standards Activity?	Internal Funding Project # [redacted]

Technical Information

Brief Description of the Invention

We propose a cellular system based on an OFDM (orthogonal frequency division multiplexing) implementation where the the transmission from different base stations are synchronized to the same clock. We assume frequency reuse factor equal to one (no frequency reuse). The transmission in downlink employs space-time block codes. We demonstrate that out-of cell interference can be effectively rejected by employing novel techniques that use the structure of space-time block codes.

Problems Solved by the Invention:

The most important source of noise in a cellular system is interference. In the absence of out-of-cell and inter-cell interference, the capacity of wireless systems is limited only by the thermal noise and is extremely large.

In this invention interference cancellation technique for multiple-input, multiple-output orthogonal frequency division multiplexing system is proposed. Moreover, we proposed the use of space-time block codes at the base station with interference suppression techniques appropriate to space-time block codes.

In conclusion, because of the the choice of OFDM framework, it was shown that the interference from neighbouring base stations can be suppressed while achieving transmit antenna diversity. We believe that this substantial advantage can be used to provide much higher data rates, that required for wireless internet.

Solutions that have been tried and why they didn't work

The conventional interference cancellation techniques assumed a single transmitted and multiple received antenna system, therefore cannot applicable to MIMO system. Moreover, conventional technique does not exploit the STBC structure. This leads to performance degradations.

Specific elements or steps that solved the problem and how they do it

Please see attachment.

Commercial value of the invention to Nortel and Nortel's major competitors

It is clear there is a need for high capacity communication scheme to support future mobile multimedia communication. One approach to achieve this capacity is to use multi-antennas at both the transmit and receive sides and using OFDM technology. However demodulating the multi-antenna transmitted signals in the presence of cochannel interference is a challenging signal processing task. The proposed scheme is an attempt to address these challenges. The performance improvement obtained by the proposed scheme will enhance the capacity and quality of the wireless link.

EXHIBIT D

Bandwidth Efficient High Data Rate Wireless System Based on Space-Time Block Coded OFDM, no Frequency Reuse and Interference Suppression Techniques

V. Tarokh T. Ratnarajah and W. Tong

[redacted]

Abstract

We propose a cellular system based on an OFDM (orthogonal frequency division multiplexing) implementation where the the transmission from different base stations are synchronized to the same clock. We assume frequency reuse factor equal to one (no frequency reuse). The transmission in downlink employs space-time block codes. We demonstrate that out-of cell interference can be effectively rejected by employing novel techniques that use the structure of space-time block codes.

1 Introduction

The most important source of noise in a cellular system is interference. In the absence of out-of-cell and inter-cell interference, the capacity of wireless systems is limited only by the thermal noise and is extremely large.

For any receiver, interference can be either caused by out of cell transmitters operating on the same frequency, or by transmitter(s) operating in the same cell. In some occasions, echoes of the signal destined to a user can cause interference (in the form of ISI). This scenario will be referred to as *self-interference*. In other cases, signals destined to other receivers are the cause of interference. In addressing the issues of interference, communication theorists have produced a substantial amount of literature.

A standard approach to combat interference is to share time, frequency and spatial resources amongst different users. A standard example is the so-called frequency planning technique where the neighbouring cells do not operate on the same frequency at the same time. This approach is

employed in the current TDMA systems, but is far from being efficient as it suffers a bandwidth penalty.

An interesting approach to combat interference in cellular systems is multiuser detection (MUD) in combination with CDMA. This is hard to implement at the receiver end, since the transmission from different base stations do not arrive synchronously at the receiver. Moreover, the remote units are usually small and power limited, making it difficult to implement algorithms requiring a large amount of computation such as MUD techniques.

Affiliated with the use of CDMA is self-interference and the interference from the signals destined to other users within the same cell. This can be overcome to some extent if the transmission sequences for different users within a cell are orthogonal (as is the case in the HDR system). However, out of cell interference remains a major issue. In the HDR system, more than half of the users experience signal to interference plus noise ratios (SINR) of less than zero dB. This limits the data rates that can be provided to these users if the system treats the interference as noise.

An efficient cellular system should enjoy frequency reuse factor equal to one, meaning that all the available bandwidth is used in every cell. Such an implementation reduces the SINR of the users closer to the edge (border) of each cell. For these remote units, the desired signal has almost the same power as the signals transmitted from the neighbouring base stations, since the distances of the unit from these transmitters are almost equal. If the interference is treated as noise, this low SINR limits the data rate that can be provided to these remote units. Because of the *fairness factor* of the system, admission of these remote units into the system will limit the maximum throughput of the system. Hence, even those remote units enjoying strong SINR will be penalized. This can make the system highly inefficient.

It may seem that the aforementioned problem can be overcome by rejecting the users with low SINR. This is not a practical solution, as any commercial wireless data solution has to be able to provide services to users at any location in the cell. In this light, a solution must be provided that improves the data rate of the users at the edge of each cell even in the presence of strong interference. *This is an issue addressed in the present document.*

Another major impairment of wireless channels is *fading*. Fading is caused by the destructive addition of the reflections of the desired signal. When a receiver is in fade, it cannot receive the desired signal. The resource to combat fading is called *diversity*. By diversity, we mean that another replica of the desired signal is provided to the receiver in another format. Diversity resources include

- temporal diversity, where another replica of the transmitted signal is sent to the receiver at

another time,

- frequency diversity, where another replica of the transmitted signal is sent to the receiver in another frequency, and
- spatial diversity, where multiple transmitter (Tx) and receiver (Rx) antennas are used for sending/receiving another replica of the transmitted signal.

Temporal and frequency resources are precious. In this light, spatial diversity is an interesting resource as it does not have a time and frequency penalty. In order to benefit from spatial diversity, Rx antennas should not be too close to each other or else must use different polarization. Similarly, there must be a reasonable distance between the Tx antennas. Because of the limitation on the size of remote units, only a limited number of receive antennas can be used. The deployment of multiple transmit antennas is relatively easier, as the cost of the deployment can be amortized between many users. Another ingredient of this work, is the *use of multiple Tx antennas at the base station and multiple Rx antennas at the remote units with the combination of appropriate coding techniques* [6]. This reduces the effect of fading significantly.

In order to combine the benefit of multiple antennas with interference suppression, we will use *OFDM* (orthogonal frequency division multiplexing) as our preferred transmission scheme. Such an implementation greatly reduces self interference (ISI) as well as synchronization problems and makes it much easier to implement multiuser detection (MUD). Indeed, *we will argue that MUD fits much easier in an OFDM implementation compared to CDMA*. Surprisingly, most of the existing literature on MUD considers a CDMA framework.

The combination of spatial diversity, MUD in an OFDM framework, and the abolishment of frequency reuse is the point of departure of our proposed system from the existing systems. These enhancements make our system very suitable for providing high wireless data rates.

2 The Proposed System

Our proposed system uses OFDM [4] for downlink transmission. We further assume that all the base stations use all the available bandwidth for transmission and that all the stations are synchronized to the same clock. Each base station is equipped with n Tx antennas and each remote unit is equipped with m Rx antennas. OFDM transmission in downlink is done using N tones. At each time $t = 0, T, 2T, \cdots$, data bits $\mathrm{b}(t)$ (not necessarily having the same number of bits) arrive at the

encoder of each base station $B_l, l = 1, 2, \cdots, L$. The ensemble of these data bits $\mathrm{b}(0), \mathrm{b}(T), \mathrm{b}(2T), \cdots$ choose n blocks of N constellation symbols $c_{1,i,B_l}(t)c_{2,i,B_l}(t)\cdots c_{N,i,B_l}(t)$, $i = 1, 2, \cdots, n$ for each time $t = 0, T, 2T, \cdots$. Each block of N symbols is the input to an IFFT device. To the output of the IFFT symbol a cyclic extension of length M is appended to produce a time domain symbol. This procedure produces n time domain symbols and these symbols are modulated and transmitted simultaneously from the n transmit antennas. Let us assume that each OFDM symbol has duration T and the time length of the cyclic extension in each OFDM symbol is ν.

The transmitted signals arrive at the receiver after traveling through the wireless channels. At the receiver, the received signal of each Rx is first down-converted. The cyclic prefix is removed. The remaining N samples are the input to an FFT device. Assuming that the delay spread of the channel is less than ν and the k-th output of the FFT device of the Rx chain j is given by $r_{k,j,B_l}(t)$, and ignoring the effect of the interference from the signals transmitted from other base station, we have

$$r_{k,j,B_l}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_l}(t) c_{k,i,B_l}(t) + \eta_{k,j}(t), \qquad (1)$$

where $\alpha_{i,j,B_l}(t)$ is the complex number representing the total effect of the channel from Tx antenna i of base station B_l to Rx antenna j at time t and $\eta_{k,j}(t)$ is Gaussian noise. Throughout this work, it will be assumed that $\alpha_{i,j,B_l}(t)$ is constant during the transmission of a symbol.

3 Interference

In this section, we will consider the effect of the interference from other base stations on the users close to the edge of each cell. To begin with, let us recall that the wireless channel is a linear channel and therefore the signals transmitted from different base stations superpose linearly in the transmission media. In the previous section, it was discussed that the contribution of the signals transmitted from base station B_l to the k-th output of the FFT device for the Rx chain j of the receiver is given by Equation (1), provided that the delay spreads $\Delta(i, j, B_l), i = 1, 2, \cdots, n$ of the channels from the Tx antennas $i = 1, 2, \cdots, n$ of base station B_l to the Rx chain j of the receiver are less than the cyclic prefix duration ν.

Let us suppose the receiver is synchronized to the transmissions from base station B_l. Because the distance of the receiver from the base station $B_{l'}$ and the base station B_l are different, there is a time difference $t_{l'}$ between the times that it takes for the elctromagnetic waves to travel from respectively

base station $B_{l'}$ and B_l to the receiver. Because of the time difference $t_{l'}$, signals from the Tx chains $i = 1, 2, \cdots, n$ of base station $B_{l'}$ arrive within at most the time period $t_{l'} + \Delta(i, j, B_{l'})$, $i = 1, 2, \cdots, n$ from the sampling instances at the Rx chain j. Provided that $t_{l'} + \Delta(i, j, B_{l'}) \leq \nu$ for $i = 1, 2, \cdots, n$, the contribution of the signals transmitted from base station $B_{l'}$ to the k-th output of the FFT device of the Rx chain j is given by

$$r_{k,j,B_{l'}}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_{l'}}(t) c_{k,i,B_{l'}}(t), \; j = 1, 2, \cdots, m, \tag{2}$$

where $\alpha_{i,j,B_{l'}}(t)$ is the complex number representing the total effect of the channel from Tx antenna i of base station $B_{l'}$ to Rx antenna j at time t. It will be assumed that $\alpha_{i,j,B_{l'}}(t)$ is constant during the transmission of a symbol.

An important observation is made next. Let us consider two neighbouring cells corresponding to the base stations B_l and $B_{l'}$. If the remote unit considered above is close to the boundary of these cells, then it has almost the same distance from B_l and $B_{l'}$. We conclude that the time difference $t_{l'}$ is small. This means that if the system is designed such that the duration of the cyclic prefix is slightly larger than the typical delay spreads observed in the propagation environment, then the contribution of the signals transmitted from $B_{l'}$ to the k-th output of the FFT device of the Rx chain j is given by Equation (2). The contributions of the base stations far from the remote unit are small and thus the k-th output of the FFT device of the Rx chain j is approximately given by

$$r_{k,j}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_l}(t) c_{k,i,B_l}(t) + \sum_{B_{l'}} \sum_{i=1}^{n} \alpha_{i,j,B_{l'}}(t) c_{k,i,B_{l'}}(t) + \eta_{k,j}(t), \tag{3}$$

where $B_{l'}$ runs in the set of all the neighbouring base stations of B_l.

The above equation is remarkable in the sense that *the interference and the desired signal are synchronized.* This is not the case for CDMA systems! *An important conclusion to be made here is that OFDM is a much more appropriate framework for multiuser detection and interference suppression techniques than CDMA.* This observation was first made in [2].

Whenever the remote unit is much closer to the base station B_l than other base stations, then the interference is small and may be treated as noise. Even for these users, if the cyclic prefix time is moderately large, the interfering signals can be treated as synchronous interference and the technique we propose in the next section can potentially provide significant improvements.

4 Space-Time Block Coded interference Suppression

We next consider the use of space-time block codes [1, 5] in the above scenario. Space-time block codes are interesting, because they provide remarkably simple decoding algorithm based only on linear processing at the receiver. Moreover, they support a simple interference suppression algorithm [3].

To keep the presentation simple, we assume that the number of Tx antennas $n = 2$, but the generalization to higher numbers of antennas is straightforward. We assume that the signal constellation has 2^b elements. We will only present the results for the uncoded case, as the generalization to the coded case is straightforward. Indeed any coding scheme can be concatenated with the transmission strategy described below.

At the encoder, at times $t = 0, 2T, 4T, \cdots$, a block of $2bN$ bits $\mathbf{b}(t)$ arrive at the encoder of base station B_l. These $2bN$ bits pick up two blocks of length N of constellation symbols $s_{1,1,B_l}(t), s_{2,1,B_l}(t), \cdots, s_{N,1,B_l}(t)$ and $s_{1,2,B_l}(t), s_{2,2,B_l}(t), \cdots, s_{N,2,B_l}(t)$. The encoder now lets

$$c_{i,1,B_l}(t) = s_{i,1,B_l}(t), \tag{4}$$

$$c_{i,2,B_l}(t) = s_{i,2,B_l}(t), \tag{5}$$

for $t = 0, 2T, 4T, \cdots$, $i = 1, 2, \cdots, N$ and

$$c_{i,1,B_l}(t) = -s^*_{i,2,B_l}(t-T), \tag{6}$$

$$c_{i,2,B_l}(t) = s^*_{i,1,B_l}(t-T), \tag{7}$$

for $t = T, 3T, 5T, \cdots$, $i = 1, 2, \cdots, N$ (see Section 2). This is precisely the scheme of [1] applied to each carrier. The transmission and reception is now done as described in Section 2. It will be assumed that all the base stations use space-time block coding for downlink transmission. As in previous sections, it will also be assumed that all the base stations are synchronized to the same clock.

At the remote unit, following the application of FFT, the k-th output of the FFT device of the Rx chain j of the remote unit is given by:

$$r_{k,j}(t) = \sum_{i=1}^{n} \alpha_{i,j,B_l}(t) c_{k,i,B_l}(t) + \sum_{B_{l'}} \sum_{i=1}^{n} \alpha_{i,j,B_{l'}}(t) c_{k,i,B_{l'}}(t) + \eta_{k,j}(t), \tag{8}$$

where $B_{l'}$ runs in the set of all the neighbouring base stations of B_l (see Section 3).

In particular

$$r_{k,j}(0) = \alpha_{1,j,B_l}(0)s_{k,1,B_l}(0) + \alpha_{2,j,B_l}(0)s_{k,2,B_l}(0) + \sum_{B_{l'}} \left(\alpha_{1,j,B_{l'}}(0)s_{k,1,B_{l'}}(0) + \alpha_{2,j,B_{l'}}(0)s_{k,2,B_{l'}}(0)\right) + \eta_{k,j}(0), \quad (9)$$

and

$$r_{k,j}(T) = -\alpha_{1,j,B_l}(T)s^*_{k,2,B_l}(0) + \alpha_{2,j,B_l}(T)s^*_{k,1,B_l}(0) + \sum_{B_{l'}} \left(-\alpha_{1,j,B_{l'}}(T)s^*_{k,2,B_{l'}}(0) + \alpha_{2,j,B_{l'}}(T)s^*_{k,1,B_{l'}}(0)\right) + \eta_{k,j}(T). \quad (10)$$

We assume that $\alpha_{i,j,B_l}(0) \simeq \alpha_{i,j,B_l}(T)$ for $i = 1, 2$ and $\alpha_{i,j,B_{l'}}(0) \simeq \alpha_{i,j,B_{l'}}(T)$ for $l' \neq l$ and $i = 1, 2$. This is equivalent to the assumption that the channels from Tx antennas of base stations to the Rx antennas of the remote unit do not change significantly over the period of two OFDM symbols. This is a reasonable assumption given the parameters of practical OFDM systems and the speed of remote units.

For notational simplicity, we let

$$h_{i,j,l} = \alpha_{i,j,B_l}(0) = \alpha_{i,j,B_l}(T), \quad (11)$$

$$h_{i,j,l'} = \alpha_{i,j,B_{l'}}(0) = \alpha_{i,j,B_{l'}}(T), \quad (12)$$

then the above equations are written as

$$r_{k,j}(0) = h_{1,j,l}s_{k,1,B_l}(0) + h_{2,j,l}s_{k,2,B_l}(0) + \sum_{l'} \left(h_{1,j,l'}s_{k,1,B_{l'}}(0) + h_{2,j,l'}s_{k,2,B_{l'}}(0)\right) + \eta_{k,j}(0), \quad (13)$$

$$r_{k,j}(T) = -h_{1,j,l}s^*_{k,2,B_l}(0) + h_{2,j,l}s^*_{k,1,B_l}(0) + \sum_{l'} \left(-h_{1,j,l'}s^*_{k,2,B_{l'}}(0) + h_{2,j,l'}s^*_{k,1,B_{l'}}\right) + \eta_{k,j}(T). \quad (14)$$

Letting

$$\mathbf{H}_{j,l} = \begin{pmatrix} h_{1,j,l} & h_{2,j,l} \\ -h^*_{2,j,l} & h^*_{1,j,l} \end{pmatrix}, \quad (15)$$

$$\mathbf{H}_{j,l'} = \begin{pmatrix} h_{1,j,l'} & h_{2,j,l'} \\ -h^*_{2,j,l'} & h^*_{1,j,l'} \end{pmatrix}, \quad (16)$$

$$\mathbf{s}_{k,l} = \begin{pmatrix} s_{k,1,B_l}(0) \\ s_{k,2,B_l}(0) \end{pmatrix}, \quad (17)$$

$$\mathbf{s}_{k,l'} = \begin{pmatrix} s_{k,1,B_{l'}}(0) \\ s_{k,2,B_{l'}}(0) \end{pmatrix}, \tag{18}$$

$$\boldsymbol{\eta}_{k,j} = \begin{pmatrix} \eta_{k,j}(0) \\ \eta^*_{k,j}(T) \end{pmatrix}, \tag{19}$$

and

$$\mathbf{r}_{k,j} = \begin{pmatrix} r_{k,j}(0) \\ r^*_{k,j}(T) \end{pmatrix}, \tag{20}$$

we can write the above equations as

$$\mathbf{r}_{k,j} = \mathbf{H}_{j,l}\mathbf{s}_{k,l} + \sum_{l'} \mathbf{H}_{j,l'}\mathbf{s}_{k,l'} + \boldsymbol{\eta}_{k,j}, \tag{21}$$

for $j = 1, 2, \cdots, m$.

For $m = 2$, and one interfering base station, the above equations are similar to the equations (15) and (19) of [3]. Naguib et al. consider a TDMA system where synchronization of the interfering and the desired signals is extremely difficult. Naguib [3] proves that assuming perfect synchronization of the interfering and the desired signals, given $m \geq 1$ receive antennas, the remote unit is able to completely suppress signals transmitted from all the Tx antennas of $k < m$ interfering base stations while obtaining a diversity advantage of $2(m - k)$. A simple zero forcing algorithm is also provided in [3]. This simple method preserve the benefits of Tx diversity for each user while suppressing the interference. Furthermore, an MMSE simple interference suppression algorithm is given in [3] that reduces the interference from interfering base stations and can provide a better performance than the aforementioned zero forcing algorithm when the SINR of the remote station is relatively large.

Because, our OFDM approach combined with space-time block coding provides perfect synchronization of the interfering and the desired signals, all the methods proposed in [3] easily apply to our case. Indeed, although Naguib's algorithms are proposed for TDMA systems, it turns out that they are *more natural to an OFDM framework* since OFDM naturally provides synchronization of the interfering and the desired signals. The MMSE approach of Naguib [3] has the zero-forcing approach as its subset and is therefore uniformly applicable to the remote units closer to the border of neighbouring cells and also to the remote units enjoying stronger SINR.

Alternative techniques exist in the literature that are also applicable for joint detection of the desired and interfering signals. Such techniques have been extensively studied in in the context of joint decoding and multiuser detection for TDMA and CDMA systems. Nonetheless, they are not

easily implementable in these frameworks because of lack of synchronization of the interfering and the desired signals.

5 Simulation Results

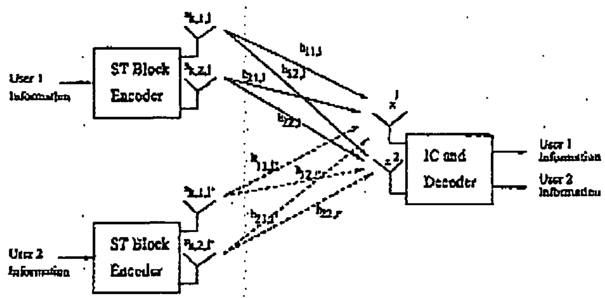

Figure 1: Transmit Diversity with STBC

Let assumed $m = n = 2$ and there is only one dominant interference, then the received signal vector $\mathbf{r}_{k,1}$ at antenna 1 is given by

$$\mathbf{r}_{k,1} = \mathbf{H}_{1,l}\mathbf{s}_{k,l} + \mathbf{H}_{1,l'}\mathbf{s}_{k,l'} + \eta_{k,1}, \quad \text{[redacted]} \tag{22}$$

Similarly, the received signal vector $\mathbf{r}_{k,2}$ at antenna 2 can be written as

$$\mathbf{r}_{k,2} = \mathbf{H}_{2,l}\mathbf{s}_{k,l} + \mathbf{H}_{2,l'}\mathbf{s}_{k,l'} + \eta_{k,2}, \quad \text{[redacted]} \tag{23}$$

The estimation problem is defined as follows:

Problem 1 *From the equations (22) and (23) estimate the information sequences of desired user ($\mathbf{s}_{k,l}$) or both users ($\mathbf{s}_{k,l}$ and $\mathbf{s}_{k,l'}$) with the arbitrary lower bit error probability.* □

There are several way of solving this problem and each one have their own advantages and disadvantages. We list the possible solutions

Solution 1 (ZF) *Zero-Forcing solution to Problem 1 is given as follows:*

$$\begin{bmatrix} \hat{\mathbf{s}}_{k,l} \\ \hat{\mathbf{s}}_{k,l'} \end{bmatrix} = \mathbf{W}_1 \begin{bmatrix} \mathbf{r}_{k,1} \\ \mathbf{r}_{k,2} \end{bmatrix} = \begin{bmatrix} \mathbf{H} & \mathbf{0} \\ \mathbf{0} & \mathbf{G} \end{bmatrix} \begin{bmatrix} \mathbf{s}_{k,l} \\ \mathbf{s}_{k,l'} \end{bmatrix} + \begin{bmatrix} \bar{\eta}_{k,1} \\ \bar{\eta}_{k,2} \end{bmatrix} \tag{24}$$

$$\text{where}\begin{cases}\mathbf{W}_1 &= \begin{bmatrix} \mathbf{I} & \mathbf{H}_{1,l'}(\mathbf{H}_{2,l'})^{-1} \\ -\mathbf{H}_{2,l}(\mathbf{H}_{1,l})^{-1} & \mathbf{I}\end{bmatrix} \in \mathcal{C}^{4\times 4} \\ \mathbf{H} &= \mathbf{H}_{1,l} - \mathbf{H}_{1,l'}(\mathbf{H}_{2,l'})^{-1}\mathbf{H}_{2,l} \\ \mathbf{G} &= \mathbf{H}_{2,l'} - \mathbf{H}_{2,l}(\mathbf{H}_{1,l})^{-1}\mathbf{H}_{1,l'}\end{cases}$$

□

Solution 2 (MMSE) *The MMSE solution for estimating the desired signal to the Problem 1 is given by:*

$$\hat{\mathbf{s}}_{k,l} = \mathbf{W}_2^H \begin{bmatrix}\mathbf{r}_{k,1} \\ \mathbf{r}_{k,2}\end{bmatrix} \tag{25}$$

$$\text{where}\begin{cases}\mathbf{W}_2 &= (\mathbf{R}_{xx} + \gamma \mathbf{I})^{-1}\begin{bmatrix}\mathbf{H}_{1,l} \\ \mathbf{H}_{2,l}\end{bmatrix} \in \mathcal{C}^{4\times 2} \\ \mathbf{R}_{xx} &= \mathcal{E}\left\{\begin{bmatrix}\mathbf{r}_{k,1} \\ \mathbf{r}_{k,2}\end{bmatrix}\begin{bmatrix}\mathbf{r}_{k,1} \\ \mathbf{r}_{k,2}\end{bmatrix}^H\right\}\end{cases}$$

□

The parameter γ in solutions 2 is called diagonal loading factor which is used to prevent the singularity due to the matrix inversion and improve the performance.

Figures (2) and (3) show the BER vs SNR plots for ETSI Outdoor to Indoor B 750 us and ETSI Vehicular B 4000 ns channel models, respectively. Both figures for 16-QAM modulation and SIR=0dB. Note that the information sequences are encoded with Turbo-code with code rate is 2/3. It is clear from the figures that significant gain can be obtained by applying combine Turbo interference cancellation technique.

6 Conclusion

We have proposed a cellular system with no frequency reuse where the transmission in downlink employs OFDM. It was argued that this implementation provides effortless synchronization of the interfering and the desired signals. We proposed the use of space-time block codes at the base station with interference suppression techniques appropriate to space-time block codes. These techniques were previously proposed for TDMA systems in [3] but are not easily implementable in TDMA framework because of the lack of synchronization of the interfering and the desired signals. Alternative detection techniques such as joint decoding can also be applied in the OFDM framework proposed in this note. These techniques will be further exploited in a subsequent memorandum.

In conclusion, because of the the choice of OFDM framework, it was shown that the interference from neighbouring base stations can be suppressed while achieving Tx antenna diversity. We believe

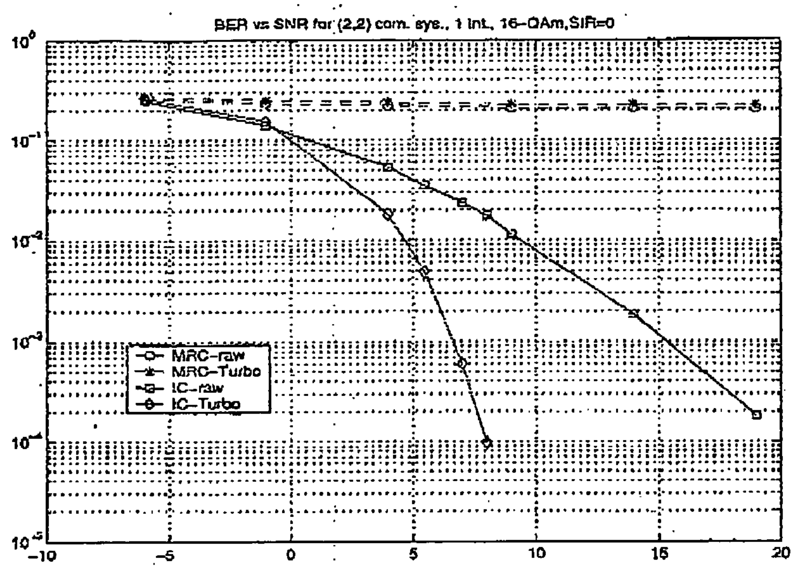

Figure 2: BER Vs SNR for comm. scheme, 16-QAM modulation and SIR=0dB

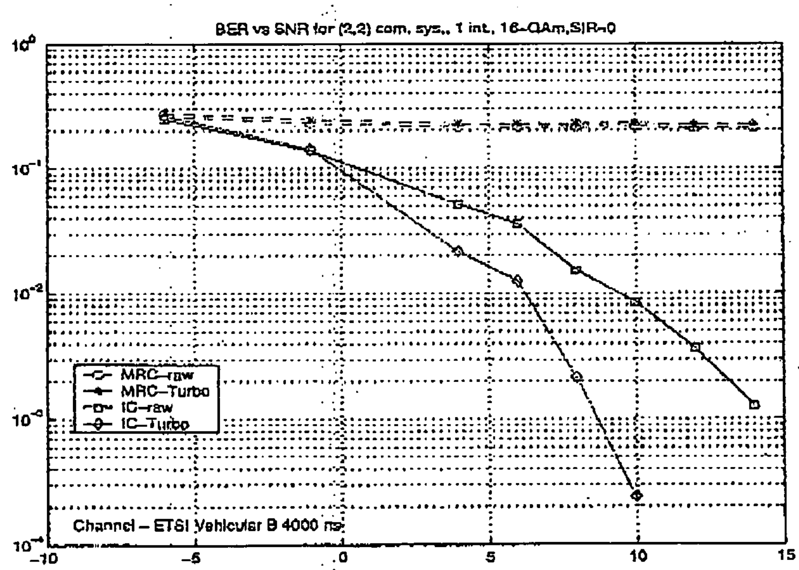

Figure 3: BER Vs SIR for (2, 2) comm. scheme, 16-QAM modulation and SIR=0dB

that this substantial advantage can be used to provide much higher data rates.

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EXHIBIT E

NORTEL NETW. .KS CONFIDENTIAL and ATTORNEY-CL. .T PRIVILEGED

INVENTION DISCLOSURE DISPOSITION (IDD)

Disclosure No.: 14545RO	Line of Business: WI
Disclosure Title: Bandwidth Efficient High Data Rate Wireless System Based on Space-Time Block Coded OFDM, No Frequency Reuse and Interference Suppression Techniques	Product Group, VP & IP Prime: CTO Wireless Internet Evolution [redacted]
Inventors: Tharamlingam Ratnarajah et al.	Reviewed By: Ottawa Patent Review Board
Product/Project: Digital Comm. & Signal Processing	Standards Related: ☐ No ☒ Yes
[redacted]	[redacted]

REVIEW SUMMARY

GIST OF THE INVENTION

Summarize within a few lines what the major thrust of the invention is *(e.g., a software program to be added to voice networks, such as Meridian, which will allow instantaneous translations from French to English).*

–Combination of spatial diversity (MIMO) and OFDM framework which results in interference suppression (frequency reuse factor assumed to be one, i.e. no reuse).

BENEFIT FROM THE INVENTION

Summarize within a few lines how the invention will benefit its target benefactor *(e.g., subscribers able to retrieve multi-lingual messages without use of additional time consuming translation processes).*

--Performance improvement enhances capacity and quality of the wireless link → fundamental concept.

Ranking/Scoring Data

a. Technological Thrust: [redacted]

b. Inventive Value: [redacted]

c. Commercial Value: [redacted]

OVERALL SCORE: [redacted]

FINAL DISPOSITION

☒ File Patent Application – Target Filing Date: 1 Oct. 2001
☐ Combine with/include in Disclosure No.: ____________
☐ Reconsider/Table (see comments below)
☐ Other (e.g., publish, Tech. Licensing, etc.)

Comments:

[redacted]

Completed by: J.K. Harit Dated: May 25, 2001

Approved by: ____________ Dated: ____________

(Revised March 16, 2001)

EXHIBIT F

7000-103

INTELLECTUAL PROPERTY LAW GROUP

Amie Kosabek

[redacted]

NORTEL NETWORKS

NORTEL NETWORKS CONFIDENTIAL &
PRIVILEGED COMMUNICATION

BY COURIER

August 28, 2001

Benjamin Withrow, Esq.
Withrow & Terranova, PLLC
201 Shannon Oaks Circle
Suite 200
Cary, NC 27511

Re: **Invention Disclosure No.: 14545ROUS01U**
Title: BANDWIDTH EFFICIENT HIGH DATA RATE WIRELESS SYSTEM BASED ON SPACE-TIME BLOCK CODED OFDM, NO FREQUENCY REUSE AND INTERFERENCE SUPPRESSION TECHNIQUES
Inventors: Tharamlingah RATNARAJAH et al.
[redacted]
Nortel Networks Servicing Agent: Jaspreet K. Harit
Required Filing Date: October 1, 2001
[redacted]

Dear Mr. Withrow:

Please find enclosed a new invention disclosure for which I would like you to prepare and file in the United States Patent and Trademark Office (USPTO) a patent application by the above-referenced filing date in accordance with Nortel Networks' guidelines.

Please ensure that when you meet with the inventors, they are advised of their responsibilities regarding their duty of candor to the USPTO, as well as any other relevant rules and/or laws including the best mode requirement.

Please send a substantially complete draft application to the Nortel Networks Servicing Agent, Jaspreet Harit, and the above-referenced inventors by **September 15, 2001**. If you foresee any problems with meeting this date or have any problems obtaining information from the inventor(s), please let me know as soon as possible.

Should you have any questions, please contact me directly.

Very truly yours,

Amie Kosabek

Amie Kosabek

Encl.: Copy of Invention Disclosure No. 14545ROUS01U
Letter regarding publication

EXHIBIT G

Withrow & Terranova

Professional Limited Liability Company

Attorneys At Law
Registered Patent Attorneys

A High Technology Patent Practice

FACSIMILE TRANSMITTAL SHEET

TO: Jaspreet K. Harit	FROM: Benjamin S. Withrow
COMPANY: Nortel Networks	DATE: August 29, 2001
[redacted]	TOTAL NO. OF PAGES INCLUDING COVER: 1
[redacted]	SENDER'S REFERENCE NUMBER: 7000-103
RE: Confirmation of receipt of invention disclosure: BANDWIDTH EFFICIENT HIGH DATA RATE WIRELESS SYSTEM BASED ON SPACE-TIME BLOCK CODED OFDM, NO FREQUENCY REUSE AND INTERFERENCE SUPPRESSION TECHNIQUES	YOUR REFERENCE NUMBER: 14545ROUS01U

☐ URGENT ☒ FOR REVIEW ☐ PLEASE COMMENT ☐ PLEASE REPLY ☐ ORIGINAL TO FOLLOW

NOTES/COMMENTS:

This fax confirms receipt of the above-referenced disclosure, and the requested filing date of October 1, 2001 is hereby acknowledged. This matter has been assigned our reference number 7000-103.

Thank you for allowing us to be of assistance in these matters.

NOTE: The information contained in this transmission is privileged and confidential and intended ONLY for the individual or entity named above. If you should receive this transmission in error, please notify our office and return to the below address via the U.S. Postal Service.

201 SHANNON OAKS CIRCLE, SUITE 200

EXHIBIT H

September 05, 2001
Wednesday

September 2001						
S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

October 2001						
S	M	T	W	T	F	S
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7	8	9	10	11	12	13
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21	22	23	24	25	26	27
28	29	30	31			

Time	
7 am	
8 00	
9 00	
10 00	
11 00	[redacted]
12 pm	
1 00	
2 00	[redacted]
3 00	Teleconference inventor for 7000-103
4 00	
5 00	[redacted]
6 00	

TaskPad

TaskPad

Notes

10/20/2005 11:11 AM

EXHIBIT I

[redacted]

P.1

Nortel Networks
Wireless

Nortel Networks
[redacted]

[redacted]

NORTEL NETWORKS
How the world shares ideas.

Facsimile

To: Ben Withrow Date: 5 Sep, 2001 Total Pages: 4

Company: Law office Fax Number: [redacted]

From: T. Ratnarajah

MESSAGE:

Dear Ben

I am hereby sending the OFDM transmitter and receiver Block diagram and related description

T. Ratnarajah

[redacted]

P.1

Nortel Networks Wireless

Nortel Networks [redacted]

[redacted]

NORTEL NETWORKS
How the world shares ideas.

Facsimile

To: Ben Withrow Date: 6 Sep, 2001 Total Pages: 2

Company: W&T PLLC Fax Number: [redacted]

From: T. Ratnarajah

MESSAGE:

Dear Ben

I am hereby sending the detail description of the equation 22 and 23, in the articaul.

T. Ratnarajah

EXHIBIT J

Withrow & Terranova

Professional Limited Liability Company

Attorneys At Law
Registered Patent Attorneys

A High Technology Patent Practice

FACSIMILE TRANSMITTAL SHEET

TO: Tharamlingam Ratnarajah	FROM: Benjamin S. Withrow
COMPANY: Nortel Networks	DATE: September 17, 2001
[redacted]	TOTAL NO. OF PAGES INCLUDING COVER: 33
[redacted]	SENDER'S REFERENCE NUMBER: 7000-103
RE: First draft of application EFFICIENT OFDM COMMUNICATIONS WITH INTERFERENCE IMMUNITY	YOUR REFERENCE NUMBER: 14545ROUS01U

☐ URGENT ☐ FOR REVIEW ☒ PLEASE COMMENT ☐ PLEASE REPLY ☐ ORIGINAL TO FOLLOW

NOTES/COMMENTS:

201 SHANNON OAKS CIRCLE, SUITE 200

EXHIBIT K

[redacted]

P.1

Nortel Networks
Wireless

Nortel Networks
[redacted]

[redacted]

NORTEL NETWORKS
How the world shares ideas.

Facsimile

To: Ben Withrow Date: 19 Sep, 2001 Total Pages: 5

Company: W&T pllc Fax Number: [redacted]

From: T. Ratnarajah (Nortel Networks)

MESSAGE:

Dear Ben

I am hereby sending my comments on the patent application.

T. Ratnarajah

EXHIBIT L

Withrow & Terranova

Professional Limited Liability Company

Attorneys At Law
Registered Patent Attorneys

A High Technology Patent Practice

FACSIMILE TRANSMITTAL SHEET

TO: Tharmalingam Ratnarajah	FROM: Benjamin S. Withrow
COMPANY: Nortel Networks	DATE: September 25, 2001
[redacted]	TOTAL NO. OF PAGES INCLUDING COVER: 4
	SENDER'S REFERENCE NUMBER: 7000-103
RE: Corrections incorporated	YOUR REFERENCE NUMBER: 14545ROUS01U

☐ URGENT ☒ FOR REVIEW ☐ PLEASE COMMENT ☐ PLEASE REPLY ☐ ORIGINAL TO FOLLOW

NOTES/COMMENTS:

201 SHANNON OAKS CIRCLE, SUITE 200
CARY, NC 27511